



## Research Article

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# Dynamic Collections: A 3D Web Infrastructure for Artifact Engagement

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**Abstract:** Archaeological collections are crucial in heritage studies and are used every day for training archaeologists and cultural heritage specialists. The recent developments in 3D acquisition and visualization technology has contributed to the rapid emergence of a large number of 3D collections, whose production is often justified as the democratization of data and knowledge production. Despite the fact that several 3D datasets are now available online, it is not always clear how the data – once stored – may be engaged by archaeology students, and the possible challenges the students may face in the learning process. The goal of the Dynamic Collections project at Lund University is to develop a novel 3D web infrastructure designed to support higher education and research in archaeology. At the onset of the COVID-19 pandemic in the spring of 2020, all teaching at Lund University moved online, reinforcing the urgency for such an infrastructure. By letting a group of students test an early version of the system as part of their online teaching, we were able to study how they used and interacted with an archaeological collection in 3D and explore the intersection of digital methods and pedagogy in archaeology. This article presents the preliminary results from this experiment.

**Keywords:** 3D collections, digital archaeology, 3D web visualization, higher education, COVID-19 pandemic

## 1 Introduction

On September 2, 2018, a fire rampaged through the National Museum of Brazil in Rio de Janeiro. In a few hours, the nation's oldest scientific institution and one of the largest reference collections of anthropology and natural history in the world was destroyed. In the previous year, around 400 artifacts dated to the Viking Age were stolen from the Bergen University Museum in Norway. Henrik von Achen, the director of the museum, declared that this was “by far the most devastating event in the 200 years of Norwegian museum history” (ICOM, 2017). When access to the material is no longer granted, documentation is the only thing left for the archaeologist. What if virtual copies of these objects had been produced and made available; what significance would that have had for students and researchers?

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In the last few years, the use of instruments and techniques for recording artifacts has grown exponentially. The awareness of the potential loss of, or restricted access to, tangible heritage has led more and more curators to employ 3D technology as a medium for documentation, preservation, analysis, and diffusion (e.g., Arnold & Kaminski, 2014). However, despite the multiple solutions offered by 3D visualization technology and the different experiments carried out so far, it is still difficult to define the role and potential that 3D archives of archaeological artifacts have in producing new knowledge. So we may ask ourselves – are these 3D archives impacting higher education and research in a significant way, and what strategies and tools should we implement for transforming these instruments into assets capable of supporting multi-modal engagement?

Three-dimensional models are rich in data and can be used for performing operations impossible to reproduce with a real object. These data allow for the identification of elements that are often invisible to more traditional analysis, providing users with the opportunity to experiment with new forms of engagement with the represented material (e.g., Campanaro, Landeschi, Dell’Unto, & Leander Touati, 2015; Dell’Unto *et al.*, 2015). These data must meet specific quality standards in order to be employed in teaching and research and need to be published using platforms capable of facilitating interaction and reuse (Dell’Unto, 2018, p. 56; Scopigno, Callieri, Dellepiane, Ponchio, & Potenziani, 2017). To be effectively used, 3D artifacts need to be Findable, Accessible, Interoperable, and Reusable (*FAIR Principles*; Wilkinson *et al.*, 2016) and should function as assets for learning, for identifying new patterns, and for defining new questions.

Digital collections of 3D artifacts thus have the potential to revolutionize the way students, teachers, and researchers understand and engage with archaeological data. However, the lack of visualization systems designed for promoting interaction prevents us from using these datasets as assets for building new knowledge. By presenting the preliminary results of the *Dynamic Collections project* which was developed at Lund University in 2018, in collaboration with the Visual Computing Lab of ISTI-CNR, Pisa, this paper describes a novel 3D web infrastructure designed for supporting and promoting higher education and research in archaeology. This platform was outlined as a future tool for an advanced level of engagement with 3D artifacts across various stages of investigation and analysis. Specifically, the system would allow teachers and students, as well as researchers, to (1) search through the archive of 3D artifacts stored on the Lund University server, (2) access and compare meta- and paradata stored with the 3D objects, (3) create and save a personal collection by selecting the objects of interests identified as the result of specific queries, (4) customize and share the collection by adding annotations at both collection and object level, and (5) engage with the 3D items through several tools constructed to support advance interaction and surface analysis.

The onset of the COVID-19 pandemic in the spring of 2020, and the experience of having to move all teaching at Lund University online, reinforced the urgency for such a tool and gave us an opportunity to test an early version of our system. Therefore, a preliminary version was made available to classes in Stone Age and Bronze Age artifact analysis on the bachelor programme in archaeology. The results of this initial testing were then used to customize the system further and define a platform capable of providing innovative and alternative tools for supporting the work of students as well as scholars. This paper presents the first implementation of the system, and it discusses the experiences and reflections collected during the tests.

## 2 Collections and 3D

*In order to achieve a definite result of a typological examination, the archaeologist must above all ensure that [...] he masters the material. He must, as far as possible, be well acquainted with all [the material] that is now available to science for the investigation of the subject* (Montelius, 1884, p. 4, transl. from Swedish).

A collection is a composition of more or less systematically arranged objects, mainly those offering a particular access to – or perspective on – history, society, art, or science. In the seventeenth and eighteenth centuries, the assemblage and curation of collections became a means to order and understand the world

and its past, and the study and teaching connected to them would lay the foundations of many of our scientific disciplines as well as their methods. It is, however, necessary to keep in mind the ways in which collections and museums have changed historically as the result of new ideas, new technologies, and new media, and how these debates have a tendency to produce binary oppositions: the material versus the immaterial, the real versus the virtual. For instance, questions have been raised concerning the authenticity of 3D objects, and whether or not their authenticity is a property of the museum object or a culturally attributed quality (e.g., Di Giuseppantonio Di Franco, Galeazzi, & Vassallo, 2018; Newell, 2012; Younan & Treadaway, 2015).

When Oscar Montelius, one of the originators of the typological method in Scandinavia, argued for the importance of collections in archaeological research, he did not concern himself with authenticity in this manner. In fact, he advocated that casts were made of important finds and these made available to key museums around Europe. To him, the scholarly access to material forms was the priority, regardless of their authenticity. Only through the extensive familiarity of the material forms would a scholar (or student) be able to access the objects' typological and chronological significance (cf. Klejn, 1982, p. 39ff.; Montelius, 1884, p. 4f.; Stig Sørensen, 1997). This emphasis on the scholarly engagement with large corpora of objects, and the tacit knowledge and experience of their forms, has characterized much of archaeological training and research since the nineteenth century, although modern archaeology tends to downplay the intuitive or impressionistic side of this approach and stress the importance of a rigorous and objective approach to object analysis (e.g., Chazan, 2019; Dannel, 1986; Malmer, 1963; Read, 2009; cf. Stig Sørensen, 1997, 2015; Wylie, 2002).

Collections and archives continue to rely on object classifications for their accessibility – on chronological cataloguing as well as groupings based on material, form, technical elements, etc. However, modern 3D visualization technology represents an additional opportunity for identifying and (virtually) sharing an even larger number of significant features and elements contained within the single artifacts with a broader, even global, community of stakeholders and provide a greater holistic access to details and perspectives of the objects otherwise inaccessible due to their fragile state or to limited visibility or access (e.g., Arnold & Kaminski, 2014, p. 79; Bustillo, Alaguero, Miguel, Saiz, & Iglesias, 2015; Wachowiak & Karas, 2009). The materiality of digital objects, and the various digital modalities through which this materiality is mediated, has furthermore the potential to counter the limitations of 2D representations so common in archaeological archives and publications (e.g., Androshchuk, 2014, p. 17f., 28; Besora et al., 2008) and allow the exploration of novel analyzes and interpretations (e.g., cf. Calpe, 2006, p. 48f.; Drennan, 2009, p. 79ff.; Hurcombe, 2007, p. 55f.; Karasik & Smilansky, 2008; Newell, 2012; Younan & Treadaway, 2015). Until now, however, much scholarly discussion has revolved around the ethics of 3D archiving, the tools and techniques available, the importance of metadata, and the sustainability of these data.

The concept of a 3D collection – being a form of *knowledge representation* (e.g., Davies, Shrobe, & Szolovits, 1993) – implies some reasoning behind the choice of the pieces, their properties and qualities (with respect to their target use), and the way they are arranged and catalogued. Most of the effort to date has been directed towards creating 3D repositories, which, no matter how well-organized they are, are not the same thing as a structured and reasoned collection built to serve as a study or reference material. The process of creating a 3D archive can be summarized into three distinct parts: (1) the artifact generation, (2) the meta- and paradata implementation, and (3) the development (or the adoption) of a visualization system used for presenting the data. All these elements are crucial parts for the creation of an archive, and in the last decade many research activities were developed to define complete pipelines of 3D digitization (e.g., the 3D-ICONS-project), to create tools for 3D web services based on standard interfaces for data repositories (e.g., ARIADNE and ARIADNEplus), to establish 3D recording as an effective process for long-term documentation (e.g., 3D-coform, scan4reco, and Carare), to construct tools based on 3D geometry, semantic metadata, and natural language processing for the reassembling of artifacts (GRAVITATE), to explore the use of artificial intelligence for the automatic identification of pottery (ArchAIDE), and to provide directions towards best practice for cultural heritage institutions, data creators, and aggregators on publishing 3D assets (Europeana pro).

Several projects have been initiated to test new forms of engagement with virtual artifacts, investigating the capacity of such tools to support teaching and research in various disciplines, as well as their shortcomings (e.g., Bustillo *et al.*, 2015; Cignoni & Scopigno, 2008; Holmer *et al.*, 2014; Kuzminsky & Gardiner, 2012; Manzano, Means, Begley, & Zechini, 2015; Means, McCuistion, & Bowles, 2013; Ponchio, Callieri, Dellepiane, & Scopigno, 2019). Among the different examples, Bonify 1.0 explores the impact of 3D web collections within zooarchaeological studies. The project underlines how virtual collections play an important role for supporting archaeological analysis and discusses how these need to reach a critical mass of objects to enable the user's engagement with the collections in a more advanced way (Nobles, Çakırlar, & Svetachov, 2019, p. 5706, 5714). This observation can be connected to another challenge identified by Star and Griesemer in their seminal article from 1989. They discussed how records produced for serving different communities of specialists tend to embody different meanings in different worlds and in order to use these records as assets – as Boundary Objects – with the purpose of establishing cross-disciplinary cooperation and communication, different stakeholders are faced with the complex task of reconciling these different meanings (cf. Huvila, Dirndorfer Anderson, Hourihan Jansen, McKenzie, & Worrall, 2017; Star & Griesemer, 1989, p. 388 with references). The standardization of methods for acquisition and visualization allows different users to find a mutual understanding and to set common tasks. The development of such processes facilitates intersection between disciplines and satisfies the needs of different specialists (Star & Griesemer, 1989, p. 388, 407, 408). However, digitized cultural heritage runs the continual risks of being preyed upon by private companies (such as Google, Sketchfab, Autodesk). Sketchfab, for example, is an online archive, utilizing an efficient 3D web viewer; it is, however, limited to the single-object browsing paradigm. Like most of the visualization solutions currently employed in this field, it is used primarily for display and provides inadequate support for more advanced engagement. What is lacking are specific tools for organizing the objects in a scientific, collection-oriented way and for working with multiple objects at the same time. What kind of tools should be included in such archival and visualization systems and what kind of engagements should be introduced to facilitate the production of interdisciplinary knowledge?

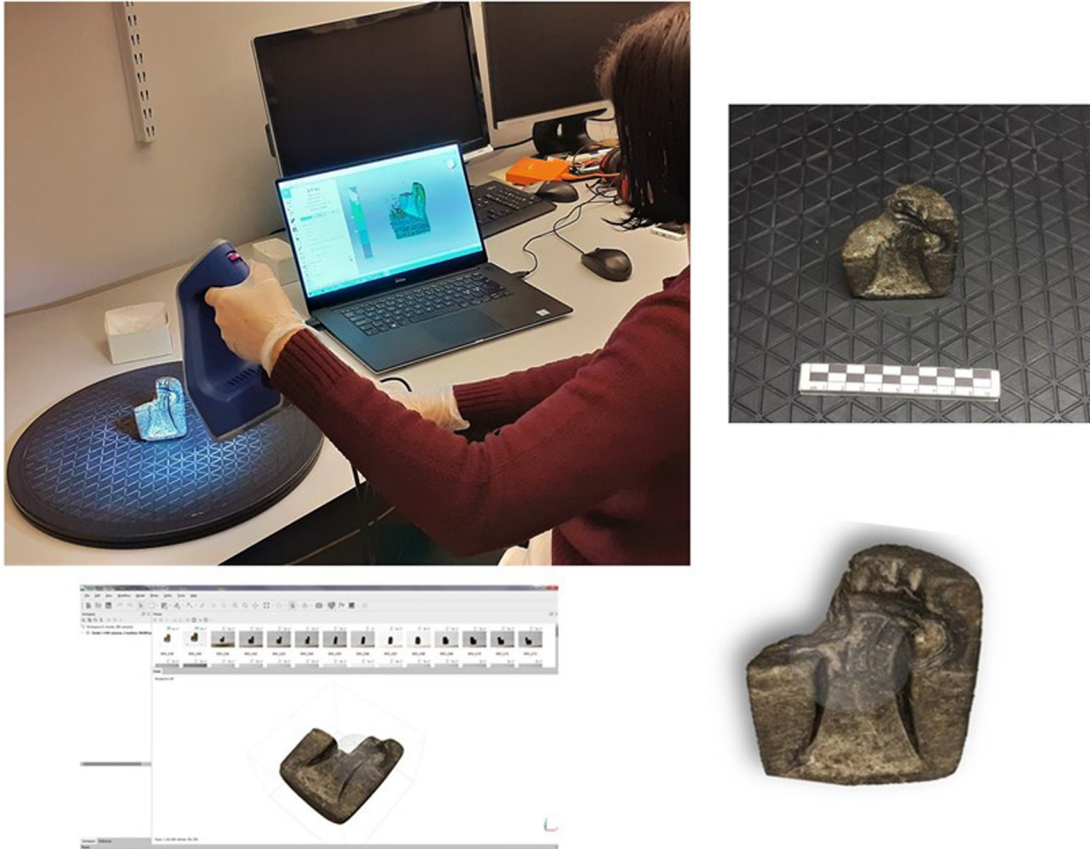
## 3 Methods, Interfaces, and Interaction

### 3.1 Digitization and Archiving

The present case study consisted of artifacts from the Scandinavian Stone and Bronze Age which are stored in the study collection at the Department of Archaeology and Ancient History in Lund. These objects are in turn on permanent loan from the Historical Museum at Lund University. After selecting the artifacts which would be used for this project, an assessment was made in order to determine which method of data acquisition would be most appropriate in each case: Range-based Modeling (RBM) and Image-based Modelling (IBM), which allowed us to gather the needed high-resolution data (Remondino & Campana, 2014; Remondino, Georgopoulos, Gonzalez-Aguilera, & Agrafiotis, 2018; Scopigno *et al.*, 2011).

The 3D scanning portion of the data acquisition was done using an Artec Space Spider scanner and Artec Eva Scanner for large artifacts. The scanner was connected to a laptop with Artec Studio 14, to visualize the scanning process in real-time and subsequently for most of the processing of the scans (Figures 1 and 2).

A Canon EOS 6D Mark II DSLR camera was used in order to acquire the photographs necessary to create 3D models via photogrammetry. For the entirety of the practical work, the camera was equipped with a 24–105 mm lens and positioned upon a tripod. The turntable and artifact being recorded were also positioned under a light tent, so that the lighting conditions could be adjusted as necessary. The photogrammetric processing was made in the software Agisoft Metashape Professional, version 1.5.2. (Figure 2). Meshlab was used as software for the final editing of the 3D models of all the artifacts created during this project, and it was within this program that thumbnail pictures of each 3D model were taken.



**Figure 1:** The acquisition of a Bronze Age mold using Artec Spider Scanner.

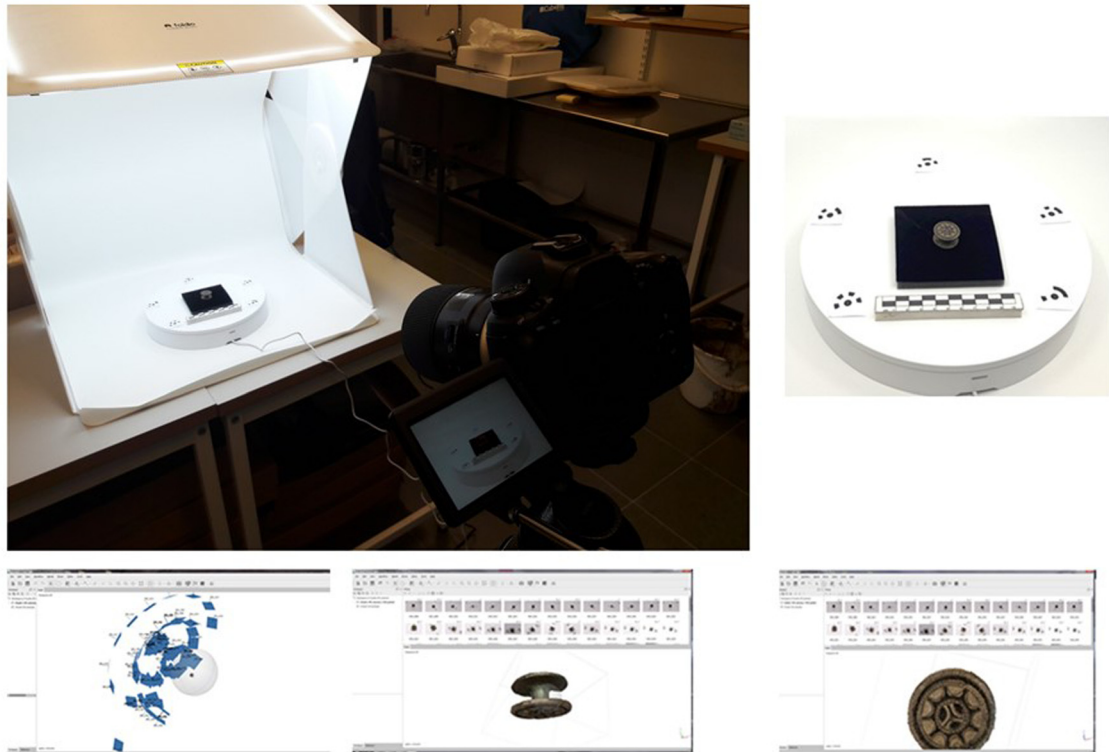
One of the goals of this project was also to identify potential issues with acquiring data for certain types of archaeological materials (i.e., artifacts with thin edges or reflective surfaces) and to subsequently develop specific protocols and workflows for these types of material. For example, the number of scans or the resolution of the fusion depended on the size of the object and the complexity of the geometry. Furthermore, the chosen camera settings had to change depending on types of artifacts, the material, color, and luster. All of this information can be seen in the paradata (see section 3.2). Once the models were completed, they were positioned/oriented using Artec software or Meshlab so that when viewed with a software such as 3DHOP they would appear oriented in accordance with standard typological representations (Håkansson, Thörn, & Linde, 1999; Högberg et al., 2000; cf. Montelius, 1917; Vang Petersen, 1999; Wyszomirska, Karsten, Friman, & Linde, 1999).

Keeping this process sustainable was one of the concerns of the project. Initially, we selected a small representative set from the collection to both test the digitization protocols and to build a “reduced” collection still usable in a class. The (pre-COVID-19) plan was then to cover, incrementally, the whole study collection at the department, and then possibly expand it by including other specimens coming from local museums and neighboring universities.

### 3.2 Visualization

The set of digitized objects is basically an archive containing the 3D data, the metadata, describing the objects from the archaeological point of view, as well as the paradata, describing the digitization process, organized in a simple database. All gathered data are accessible through a web interface. Web access is an





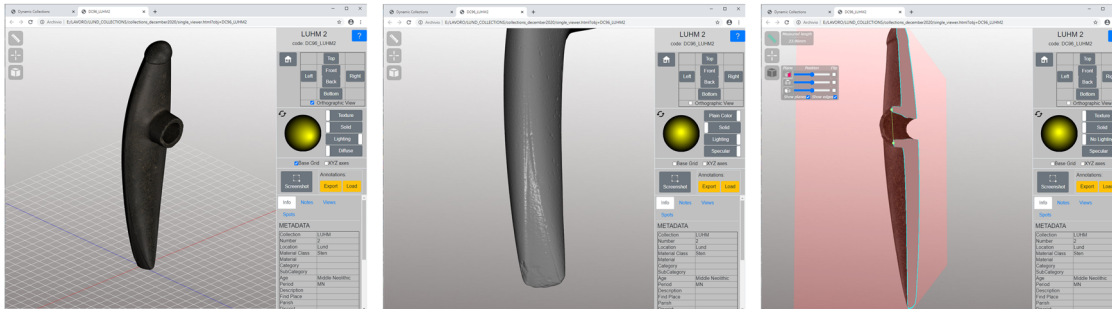
**Figure 2:** The acquisition of a Bronze Age double button using photogrammetry.

essential point in the project, as it makes possible for all the target actors to access and work with the data, fulfilling the FAIR principles.

The 3D visualization component is based on the 3DHOP tool. 3DHOP is an open-source framework for the creation of web-based visualization of complex 3D models. This tool offers a fully customizable presentation scheme, interface, and interaction instruments, making it possible to build web applications that are responding to the specific needs of each project. 3DHOP can handle extremely complex 3D geometries, unlike other solutions for 3D web publishing and archiving, by using a streaming-friendly multiresolution representation, ensuring fast network transfer and efficient rendering. The 3DHOP technology has already been used by some important cultural heritage multimedia data repositories such as UoY ADS, Deutsche Exc Cluster TOPOI, and the ARIADNE as well as ARIADNEplus projects.

The viewer uses a turntable navigation to let the users explore the object. This interaction mode is simple to use, yet a good degree of flexibility is maintained. The predefined canonical views and the orthographic mode are accessible from the interface area and can be used to replicate the standard typological representations used in books and catalogues. The different visualization options (texture, specular, transparency, lighting, light direction) help in exploring different aspects of the object and enhance the readability of the surface, allowing the user to visualize features of the artifacts not necessarily visible to the naked eye. Using the interactive cut-through, the users may also slice the object, reproducing the section outlines often used in archeological reference literature. The viewer furthermore provides basic measurement capabilities and display the meta- and paradata of the object, for reference (Figure 3).

As a final note, we should mention that the main goals for this first acquisition campaign were essentially to populate the archive and test the functionalities of the system. The onset of the COVID-19 pandemic, however, forced us to accelerate the process in order to provide objects for the necessary online classes. For these reasons, we focused on covering a wide variety of objects instead of concentrating on fewer, but more accurate, models. When evaluating the produced models, we found problems with some of the objects, especially caused by challenging materials and surfaces. Color fidelity is another issue; the



**Figure 3:** The 3D viewer offers several tools and rendering modes to effectively explore the object.

texture generated by the scanner is often not sufficiently detailed, and in some cases we could have used a better color calibration of the input photos. Additionally, the WebGL rendering is not constructed to offer an accurate color management. Our future plan is therefore to go through the difficult models, isolate the problems, and introduce additional digitization, integration, and processing steps in order to enrich our working protocols. All these steps of data integration will be available as paradata for the individual objects. We will then replace the models with more accurate ones as soon as they are ready.

## 4 Implementation in Teaching

The early implementation forced by the COVID-19 pandemic allowed us to observe and assess the usability of the rendered 3D models and the above-mentioned interface. This was done on the basic level course ARKA21 (the first semester of the BA programme) in Archaeology, which contains two consecutive modules dedicated to the cultural history and material culture of the Scandinavian and European Stone and Bronze Ages. The structures of these two modules, the Stone Age and the Bronze Age, are very similar. They consist of lectures on the cultural-historical trajectory of each period, artifact studies, museum visits, and field trips. The students are examined in similar ways in both modules, through a take-home exam and an artifact exam. This structure was interrupted when all campus-based teaching at Lund University moved online on March 18, 2020, less than a week before the Stone Age module started. This sudden shift naturally affected the planning, organization, and implementation of all teaching activities, particularly the artifact training that forms an integral part of the course. But it also offered an opportunity to start testing the implementation of our online 3D collections in our teaching. Unfortunately, at that time, the system was far from ready, so all the teaching had to be carried out without the access pages, only using an initial version of the object viewer page.

### 4.1 Rethinking Artifact Studies

The ordinary, campus-based artifact studies on these modules usually consist of chronologically or thematically ordered sessions, containing an introduction by the teacher followed by a workshop where the students review artifacts from the relevant time period, physically handle them, look up references in publications and visual guides, and discuss with their peers.

The artifacts used in these sessions come from the department's study collection, as mentioned above. Historically, this collection was used to instruct the students in diagnostic typologies and chronology. But since the 1990s, the archaeological teaching in Lund has seen a gradual transition towards the so-called *learning paradigm* (Barr & Tagg, 1995), with an increasing emphasis on how students, as learners, *construct* their knowledge. The study collection has since then been employed more in line with the pedagogical

principles of *object-based* and *experiential* learning (Chatterjee & Hannan, 2015; Hein, 1998; cf. Kolb, 1984; Romanek & Lynch, 2008), where the students' active engagement with artifacts not only trains them to identify, name, and date the types, but also expands their multimodal literacy in reading material culture by letting them explore ways in which various material features may convey meaning.

The artifact studies are thus conditioned on physical engagement with as many objects and types as possible in order to achieve both discursive and nondiscursive understanding of the material variability of the archaeological period in question. The Stone Age module furthermore includes a theme day on flint, including introductions to knapping, refitting, and usewear analysis (Figure 4).

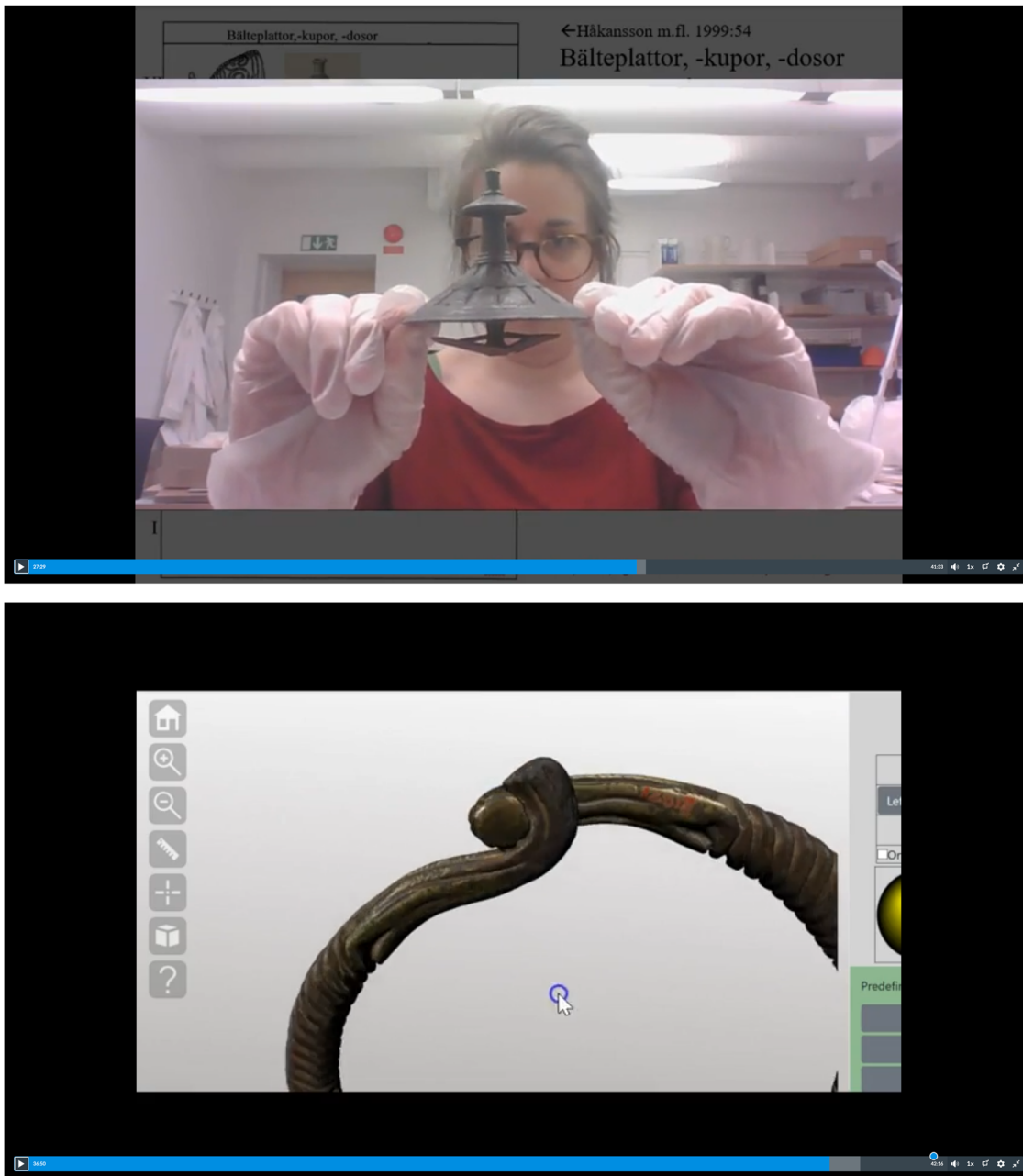
The new, pandemic-adjusted structure removed many of the opportunities to physically and collaboratively engage with the collection. The face-to-face interaction between teachers and students was replaced



**Figure 4:** The physical engagement with materials and artifacts composes a vital part of the pedagogical framework on the courses in archaeology at Lund University. Photos by Åsa Berggren and Fredrik Ekengren.



by prerecorded lectures and tutorials where the teachers described or demonstrated the important morphological attributes (Figure 5). Furthermore, each module included websites with a selection of 3D models in 3DHOP of relevant artifacts from the study collection, and the students were introduced to the interface via a short tutorial video. In the case of the Bronze Age module, the students were also offered a set of self-study questions and exercises intended to help them learn the artifacts. Besides the online teaching, a set of voluntary self-study sessions were organized on campus which allowed the students to access the whole study collection in small groups. Instead of museum visits, links to online museum exhibitions at the National Museum in Copenhagen and the Historical Museum in Lund were provided.



**Figure 5:** One of the teachers, Stella Macheridis, used prerecorded tutorials on Canvas – the online educational platform used by Lund University – to demonstrate the morphologies of Bronze Age artifacts.

## 4.2 Examination and Student Results

The knowledge of the typical artifacts of each period is commonly examined through an “artifact exam” on campus, where the students have to identify and date a certain number of artifacts. The pandemic-adjusted exam, on the other hand, was based on 3DHOP models with questions using the timed quiz function in Canvas – the online educational platform used by Lund University. Each of the questions was connected to a 3D model of an anonymized artifact, which the student had to identify.

Overall, the results of the two artifact exams were poor in comparison to previous, campus-based semesters. The result of the Stone Age exam showed that only three of 14 students who took the first exam passed (two of these three were close to getting all answers correct). Of the nine students that took the re-exam one week later, five passed. Only two students took the second re-exam three months later and one of them passed. In all, the total number of students that passed the artifact part of the Stone Age course was 9 of the 14. The results of the Bronze Age artifact exam showed that 8 of 11 students passed it in the first attempt, a clearly better result than for the Stone Age module, but not as high as expected.

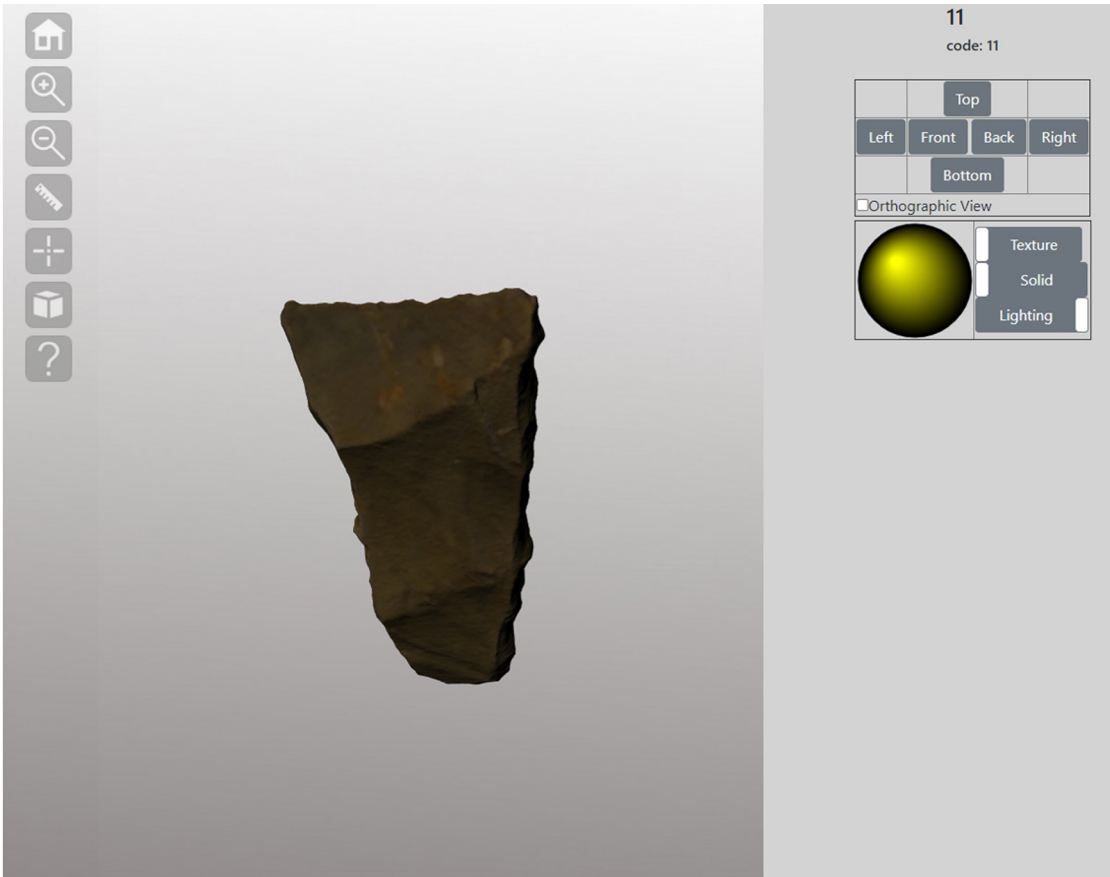
Why did so many of the students fail, especially the initial Stone Age artifact exam? This mode of examination was challenging for a number of reasons. First, since the unobserved digital form of examination increased the risk of cheating, specific time restraints had to be implemented. This, in turn, most likely meant an increased level of stress that negatively affected the performance of some of the students. By switching the focus of the digital exams in the future, and designing them as open lab-assignments instead, the stress and risk of cheating might be avoided altogether. Second, this was the first semester of archaeology studies and some students were completely new to the University and had limited experience of appropriate study techniques. Third, the pandemic itself added a layer of stress and anxiety that naturally affected their performance. However, in the present paper we will turn our focus on some of the epistemological and technical issues that also affected the student engagement and learning process.

## 4.3 Pedagogical Remarks

One of the students remarked that the 3D models started to make sense only once they had seen the objects in real life. With no prior experience of prehistoric artifacts, images and 3D models may appear too abstract to form the basis for a general understanding of the objects. On the Stone Age module, for instance, many of the artifacts were of flint – a material new to most of the students – which consequently limited their ability to understand and engage with the models. It is also clear that the students who took advantage of the self-study sessions on campus, and engaged directly with the different types of artifacts, fared better in the exam. The opportunity to physically handle the objects thus seems crucial for acquiring an understanding of the artifacts available in 3D.

In addition, one small flint arrowhead was misunderstood by almost every student as an axe, as they failed to use the measuring tool available in 3DHOP (Figure 6). This shows some of the challenges that the students faced encountering an unfamiliar material in an unfamiliar setting. Most likely, it also reflected their inexperience of reading scale. Proficiency in using a 3D interface like this is thus the result of a learning process in itself, for teachers as well as students, which affects the artifact engagement. For example, the higher success rate for the students in the Bronze Age module can, at least partially, be explained by the fact that the students had more time to familiarize themselves with the modes of online teaching, and it was their second experience with the 3DHOP system. In addition, the teacher had more time to reflect on, organize, and adapt the artifact teaching to include video tutorials that contained the demonstration of both the actual artifacts and the 3D interface (Figure 5).

Furthermore, after the Stone Age exam, some students complained that the time constraint was too tight as it took time for the 3D models to load. One student stated they could not load the models which clearly impacted their ability to see the artifacts. To prevent this problem in the Bronze Age module, access to the online collection was modified with a link that leads directly to the page for each object in order to



**Figure 6:** The model of the transverse arrowhead used in the Stone Age exam. Without a scale it may be misunderstood as a flake axe.

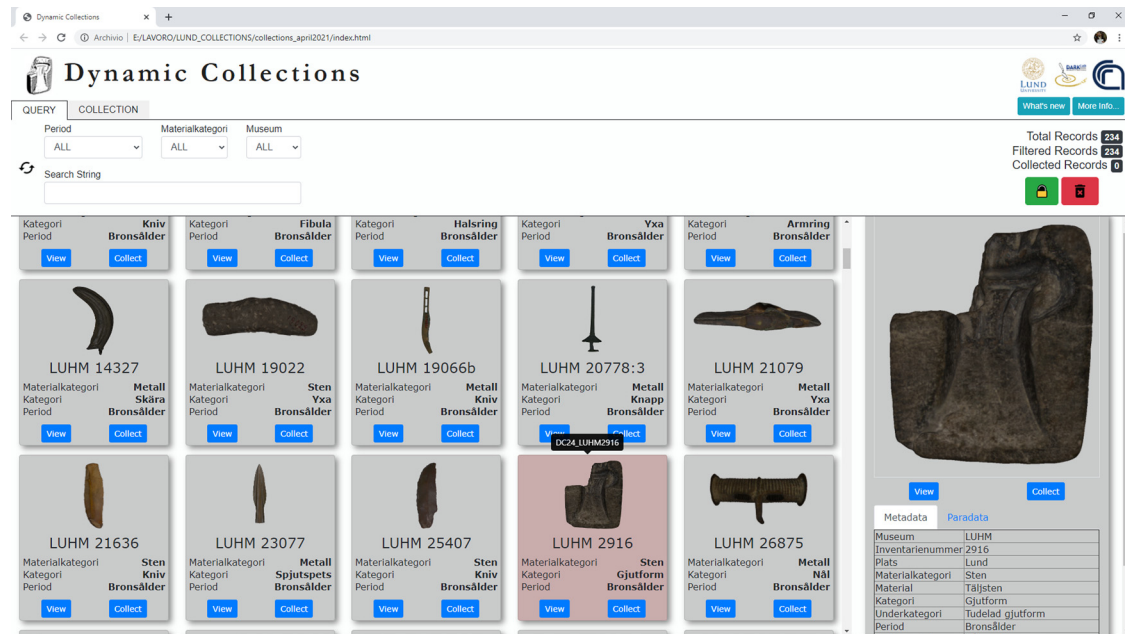
save time and computer memory. These considerations reinforce the importance of accessibility, but also points to the potential of a fully developed, web-based interface.

## 5 Outcome and Further Development

Our experiences and reflections from this very first trial-run with the system in a pedagogical setting were crucial for the further development of a prototype of the web interface tailored towards students and teachers, where we attempted to expand the possibilities for engagement with the artifacts as far as possible.

To address some of the problems that came to light during the tests, we worked on the 3D visualization, fixing platform-specific bugs, improving its speed, and adding additional helpers, like XYZ axes and a metric base grid, to provide a visual reference for the size and orientation of the objects. The system still relies on access to a high-speed internet connection, and no lower-bandwidth version of the system is planned. However, since the initial experiments, we expanded the functionalities of the web access. A beta version of the system has been launched on a fully open and freely accessible web application.<sup>1</sup> The data and metadata are stored on the servers of the Joint Faculties of Theology and Humanities at Lund University, who are also responsible for the future maintenance of the web application. The web access

<sup>1</sup> URL: <https://www.darklab.lu.se/digital-collections/dynamic-collections>



**Figure 7:** The database-like interface. Users may browse the whole repository, using filter and search tools, access each object’s meta- and paradata, launch the 3D viewer, and collect objects for their custom collection.

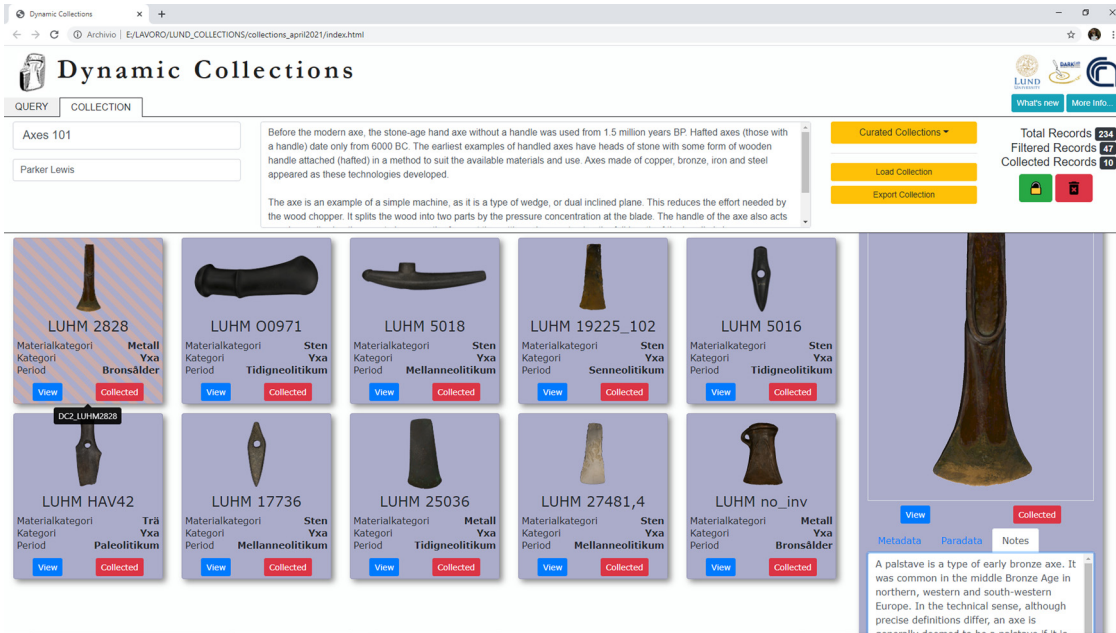
currently behaves, on one side, like a standard online database – the users may browse the archive and, using a search interface, they may query the object database to find artifacts with specific characteristics (Figure 7). All the 3D models are directly accessible from this interface, making it possible for the users to easily search and interact with any object in the archive. The interface also presents, for all the objects, their meta- and paradata, thus providing a complete description of the entity.

The other functionalities of web access are focused on the idea of “collection.” While searching the archive, the users may “collect” those artifacts they deem interesting or relevant for their work, thus forming a personal collection (Figure 8). The collected objects appear in a separate part of the interface; also, users may access all the meta- and paradata of the objects and explore their 3D models. At any time, the users can remove pieces from the collection, or return to the search interface and find new objects to add. The users may then customize the collection by giving it a name and other basic information, and by adding notes to the whole structure or to the individual objects.

This process mimics how a teacher or student would work with the physical collection – they would go through the boxes of artifacts, looking at indexes and at the objects themselves, selecting some interesting ones, and bringing them to a table to examine and take notes. A collection is thus a data structure that is built on top of the archive, and basically contains, beside a set of identification information (author, title, and so on), some notes and a list of the collected objects – each one with its associated annotations. This data structure may be saved in JSON format, and then loaded again for a new work session. This JSON file is compact, as it contains only the collection data, while all the object data (3D, meta- and paradata) still reside on the server. The users may use the JSON file to return to the same objects at a later date for continued work, or share it with other students/teachers (as course notes, assignments, study data). Since one of the purposes of the system is to be used by teachers when giving classes, they can create a collection using the interface and then publish it as a “curated collection” directly on the server, making it accessible directly from the interface, without having to distribute it as an external JSON.

The plan for the near future is to expand this collection management to include more ways to enrich the structure and to work with the collected objects. We want to add the possibility of using the collected objects to create things like schemes, spatial arrangements, and graphs. These representations would truly transform a selection of objects into a reasoned collection. Furthermore, the system only presents the “front

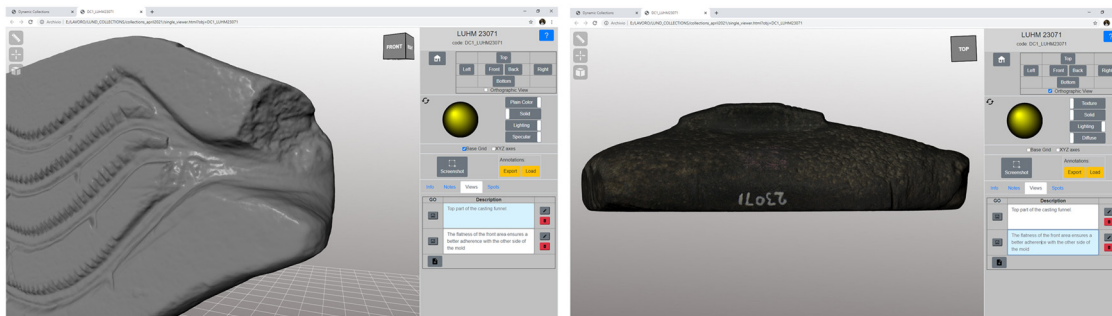




**Figure 8:** The collection interface. Here are listed the objects collected from the database-like interface. Users may give their collections a name and add notes at collection and object level. Here, collections may be saved and loaded in JSON format, or the user might access one of the *curated collections*.

end” at the moment, while all the administrative tasks (e.g., adding new objects, modifying the database, uploading the curated collections) are managed manually by the project administrators. This was another choice forced by the time constraints caused by the COVID-19 pandemic; the roadmap does, however, include a full back-end interface for the system management.

When it comes to the engagement with individual artifacts, certain steps were taken in an attempt to reduce the difficulties experienced in the teaching and facilitate a more experiential learning environment. First of all, additional measurement capabilities were added already during the spring in the form of a 1 cm scale grid below the individual object. In that way, it will be easier for the user to understand the comparable sizes of the objects analyzed. Furthermore, we have developed the possibility to add spatial annotations to the object (Figure 9). It is possible to save “view bookmarks,” containing the current view and all the visualization options, plus an associated textual note. It is also possible to add point-hotspots with a short text (to simulate small label-tags). Further annotation types will be added soon; we are for instance working on the possibility of drawing polygons and polylines directly on the 3D surface.



**Figure 9:** In the 3D viewer, *views annotations* work like bookmarks, storing a point of view and all the viewer state (rendering options), with an associated description.

These various forms of annotations may also be saved in a JSON file and loaded back, to again support the sharing of information between teachers and students. If the object viewer has been opened in a specific collection, it is possible to directly add the annotations to the collection data structure, as an annotation associated to that object. In this way, we can connect the annotation work on a specific object to the annotation work inside the collection. A teacher may thus search the archive to find the objects most suitable for a lecture, assemble them in a collection, and annotate it. This collection may then be used in class as a teaching aid and/or digitally distributed to the students as study material. A student may want to specifically search the archive to expand on what has been seen and discussed in class. They may want to create a personal collection, or to edit a teacher-created collection and add personal notes for future reference. The creation of an annotated collection may also be used by teachers as an assignment for a class – for example, tasking the student to find a number of objects showing specific characteristics, or displaying morphological changes, to add them to a collection, annotate it, and return this newly created collection to the teacher for review.

## 6 Concluding Remarks

What is clear from our experiences is that 3D models are a good complement to normal, campus-based, teaching and may serve as a vital tool when access to the physical collection is restricted (cf. Nobles *et al.*, 2019). Moreover, there are various ways in which the 3DHOP interface may be customized to facilitate engagement, specifically the production of knowledge by students and researchers. Our system thus offers a framework for exploring how complex intersections of factors influence learning and meaning-making (cf. Falk & Dierking, 2000) – something that will be further explored in future research. However, the pedagogical experience also showed us that 3D models cannot replace the tangibility of the physical objects completely (cf. Newell, 2012). There are some elements and aspects that cannot be reached visually, for example the weight of the object or the “tactile” details of the decoration and the material that are essential for recognition and classification. These are consequently aspects that need to be considered and countered as far as possible in the further development of the interface. On the other hand, the dynamic collection offers another level of engagement not possible with a physical collection. Students have access to a large corpora of objects 24 h a day; they are able to study it from home; they are able to see elements and details not easily identifiable to the naked eye; they are able to manipulate the illumination and visualization parameters with a click of a button; and they can use the annotation tools, including bookmarking and point-hotspots, to analyze the material in detail as well as share those analyzes with each other and the teacher. Thanks to the associated database which contains metadata on how the artifacts have been typologically and chronologically conceptualized by previous scholars, the students are furthermore able to make comparisons between this data and their own analyzes, as well as with other pieces in the collection. Used thoughtfully, and especially after the students have had their first physical encounter with the artifacts, the models can be used to extend their experience of the physical museum collection. Thus, the advantages of proposing the teaching of archeology through organized and thematic 3D collections are many.

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